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Refractivity Turbulence Observation Using a New Balloon-Ring Platform (Preprint)

Frank Eaton et al.

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14. ABSTRACT
This paper presents new methodology to address critical refractivity turbulence issues for laser propagation using a new measurement system-a portable "balloon-ring" platform with multiple fine wire sensors at several separations. All "raw" data is transmitted to ground station-allowing spectra to be calculated. The new platform is discussed and preliminary examples of observations, including artifacts, are shown and discussed. This new platform provides capabilities during the daytime as well as nighttime-unlike conventional thermosondes that are uses only at night. Such all time observations are important due to the pronounced diurnal variation in the planetary boundary layer where many laser systems are operated. Plans to address the longstanding concern of wake contamination on systems suspended below a balloon quantitatively will be presented. The objective of this effort is to develop the capability that can address several questions related to laser propagation auch as: 1.Is the isotrophic for the scales of intrest? 2. Is the turbulence Kolmogorov under various atmospheric conditions or how often is the structure function represented by the r2/3 law? 3. What are the profiles of inner and outer scale? 4. To what degree does wake contamination affect conventional thermosonde measurements? 5. Does fine structure within the scattering volume sensed by radar affect refractive index structure parameter and eddy dissipation rate estimates? These questions and concerns will be addressed by making the appropriate observations using the balloon-ring platform. Many of the measurements will be taken at Vandenberg AFB since the Western Test Range operates a ground receiving station, balloon launch facility. This effort provides an observation platform that will ultimately lead to the development and validation of conceptual/statistical/physical models.

15. SUBJECT TERMS
Refractive index structure parameter, eddy dissipation rate, inner and outer scales, structure function, radar, sodar, balloon-ring platform

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Refractivity turbulence observations using a new balloon-ring platform

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ABSTRACT

This paper presents new methodology to address critical refractivity turbulence issues for laser propagation using a new measurement system-a portable "balloon-ring" platform with multiple fine wire sensors at several separations. All "raw" data is transmitted to a ground station-allowing spectra to be calculated. The new platform is discussed and preliminary examples of observations, including artifacts, are shown and discussed. This new platform provides capabilities during the daytime as well as nighttime-unlike conventional thermosondes that are used only at night. Such all time observations are important due to the pronounced diurnal variation in the planetary boundary layer where many laser systems are operated. Plans to address the longstanding concern of wake contamination on systems suspended below a balloon quantitatively will be presented.

The objective of this effort is to develop the capability that can address several questions related to laser propagation such as:
1) Is the atmosphere isotropic for the scales of interest?
2) Is the turbulence Kolmogorov under various atmospheric conditions, or how often is the structure function represented by the $r^{2/3}$ law?
3) What are the profiles of inner and outer scale?
4) To what degree does wake contamination affect conventional thermosonde measurements?
5) Does fine structure within the scattering volume sensed by radar affect refractive index structure parameter (C_n^2) and eddy dissipation rate (ε) estimates?

These questions and concerns will be addressed by making the appropriate observations using the balloon-ring platform. Many of the measurements will be taken at Vandenberg AFB since the Western Test Range operates a ground receiving station, balloon launch facility, VHF radar, boundary layer radars, sodars, and instrumented towers that will enhance this effort. This effort provides an observation platform that will ultimately lead to the development and validation of conceptual/statistical/physical models.

Keywords: refractive index structure parameter, eddy dissipation rate, inner and outer scales, structure function, radar, sodar, balloon-ring platform

1. INTRODUCTION

Understanding the use of lasers in weapon systems can only be fully pursued in a field environment where the atmosphere is a central and integral part of the problem. The Directed Energy Directorate of the Air Force Research Laboratory has been involved in atmospheric turbulence studies related to laser propagation for several years. These have included aircraft and scintillometer measurements[1], aircraft and radar observations[2], measurements of turbulence using a kite and tethered blimp platform[3], and an ensemble of sensors (scintillometer, differential image motion

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monitor, sodar, and tower-mounted fine wire sensors) to examine turbulence in complex terrain.[4] The same fine wire probe systems were used on the aircraft, kite/tethered blimp experiments, and on the tower. In addition, using a nearly 6-year continuous data set at White Sands Missile Range (WSMR), VHF radar observations were analyzed to examine slant path optical turbulence conditions (transverse coherence length, isoplanatic angle, and Rytov variance),[5] examine persistent layers of enhanced C_n^2 in the lower stratosphere,[6] estimate the inner and outer scales of turbulence,[7] study gravity waves and turbulence near thunderstorms,[8] and investigate the seasonal variation of gravity wave activity at WSMR.[9] Other relevant studies include the coupling of gravity waves and turbulence,[10] examining the variations of winds and turbulence at WSMR,[11] and estimating the eddy dissipation rates[12] and diffusion coefficients at WSMR.[13] The radar observations are nearly continuous, under all weather conditions, and of high temporal (3 min) and spatial resolution (150 m height), up to 20 km altitude. Although the radar-obtained results are invaluable, the VHF system with its 500-ft diameter antenna is not portable. The balloon-ring platform is highly portable and can be used at any site worldwide.

Tiefenau and Gebbeken examined the balloon wake effect on temperature measurements compared from a sensor behind an ascending balloon and beneath a descending parachute.[14] A cooling of the balloon skin was identified at night due to adiabatic expansion and a large skin warming was found during daytime from solar heating. These temperature differences affect the temperature of the air stream passing the balloon, the wake, and ultimately affect the temperature measurements from a sonde suspended beneath the balloon. Reynolds and Lamberth examined erroneous temperature measurements with constant-level balloons.[15]

2. METHODOLOGY

All temperature and velocity data will be received by telemetry at the ground at the sampling rate (typically 3 kHz). This will then be analyzed in several ways such as calculating PSDs and structure functions for the observations of each probe. These results will display if certain atmospheric conditions produce non-Kolmogorov turbulence. From results using the various horizontal separations and vertical measurements due to the ascent of the sensors, the results will show if the atmosphere is truly isotropic or not for the scales of interest.

The WSMR VHF radar has recently been moved to Vandenberg AFB as part of the Western Test Range suite of instrumentation and will be used in conjunction with the balloon-ring system to provide C_n^2, ε, winds, etc. Models are now being developed for estimating C_n^2 by different groups, and the approach of some involves a relationship between mechanical and optical turbulence. This relationship will be examined in detail from in situ measurements taken with the balloon-ring system sensing temperature and velocity fluctuations. These high spatial resolution observations will be compared to the same radar-obtained values within the radar scattering volume to examine radar scattering mechanisms.

VanZandt et al.[16] addressed the problem regarding radar observations concerning C_n^2 and ε and they presented the relationship:

$$\varepsilon = \left(\gamma \overline{C}_n^2 \frac{N^2}{F^{1/3}} M^{-2} \right)^{3/2}$$

where γ is a "constant," $\overline{C}_n^2$ is the mean refractive index structure parameter for the radar volume, N is the Brunt Vaisala frequency $[N^2 = g(\partial \ln \theta / \partial z)]$ where z is the height and θ is the potential temperature, F represents the fraction of the radar volume which is filled by turbulence, and M is the mean potential temperature gradient. M is given as:

$$M = -77.6 \times 10^{-6} \frac{P}{T}\left(\frac{\partial \ln \theta}{\partial z}\right) \times \left[1 + \frac{15{,}500 q}{T}\left(1 - \frac{1}{2}\frac{\partial \ln q / \partial z}{\partial \ln \theta / \partial z}\right)\right]$$

where q is the specific humidity, p is pressure in millibars, and T is temperature in degrees Kelvin. The fine

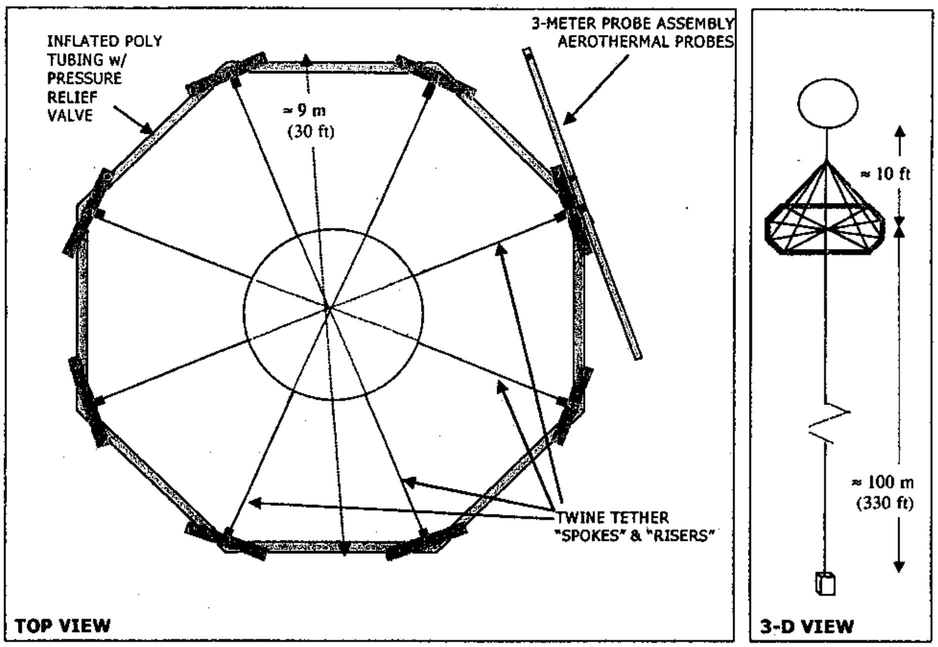

Figure 1. Schematic of balloon-ring setup. Right panel displays optional thermosonde

wire measurements used on the balloon-ring platform will provide the observations for evaluating "F" in the first equation and determining the effect on the turbulent parameters.

3. INSTRUMENTION CHARACTERISTICS AND OBSERVING SITE

A new platform was designed by Dr. Demos Kyrazis of R^3, Inc. to examine balloon wake effects using a large "ring" so that sensors mounted facing upwards on the ring will be uncontaminated by the balloon wake. A schematic of the balloon-ring design is shown in Figure 1. The right panel shows an optional configuration with a thermosonde being flown beneath the balloon for evaluation of "wake" effects. The "ring" is an inflatable polyethylene tube with a pressure relief valve. The "ring" is actually 8-sided with a diameter of about 30 feet and trails the balloon using several risers. The balloon wake passes through the center of the "ring" leaving the measurements uncontaminated. This system will be used at the Western Test Range at Vandenberg, AFB, with several fine wire (1 1/4 μm diameter) sensors, to measure high speed temperature and velocity fluctuations in conjunction with the 50 MHz radar observations. Data will be received by telemetry and a GPS unit on the package will aid in recovery. Measurements obtained from the recently installed six new boundary layer radars, six sodars, and 30 instrumented towers at the Western Test Range will also be used. A microwave refractometer, presently being developed under an SBIR program, will also be flown for direct comparison to the radar returns. The microwave refractometer will act as the "standard" for obtaining C_n^2. Balloon wake effects will be evaluated. A conventional thermosonde will be suspended below the balloon and the thermosonde-derived results will be compared to the observations from the sensors on the ring. Objectives are to examine the relationship between mechanical turbulence and optical turbulence (since this is of interest for some modeling approaches), to investigate radar scattering mechanisms, and study the turbulent characteristics of the marine boundary layer and the littoral zone. From simultaneous VHF radar and balloon-ring system observations, the refractive index structure parameter (C_n^2), the eddy dissipation rate (ε), the inner scale (l_o), and the outer scale (L_o) will be evaluated. Special attention will be taken for evaluating turbulence spectra and intermittency within, at the edge, and outside of turbulent layers. The observations will be analyzed to examine if the atmosphere is isotropic for the

scales of interest for lasers as well as determining if the turbulence is Kolmogorov under various atmospheric conditions.

The primary site at Vandenberg AFB is established and has considerable facilities (including balloon launch facility) and equipment required for the efforts described here. The site has been recently upgraded as part of the Western Test Range. The primary equipment needed for the proposed experiments (balloon-ring system and receiving system, sodars, boundary layer radars, instrumented towers, and the 50 MHz radar) exist.

4. RESULTS AND CONCLUSIONS

Figure 2 shows estimated balloon diameter from the surface to about 27.5 km altitude for a 1000 g balloon. The bounds for an adiabatic and isothermal atmosphere are also displayed. The top curve shows an estimated wake diameter at 100 m beneath the balloon over the same altitude range. Of particular interest is the sudden increase of wake diameter near 11 km. This is the altitude where the critical Reynold's number is reached with the standard atmosphere as used in this estimate. The estimated wake diameter grows from about 4m-5m rapidly and then continues to increase to about 8.5m at 25 km altitude. Figure 3 shows the CLEAR 1 C_n^2 turbulence profile. A dogleg pattern is seen at about the same altitude as found in the example showing the critical Reynold's number in Figure 2. The significance of this pattern will be investigated in future studies. Also shown in Figure 3 are two curves for two values of uniform C_T^2 converted to profiles of C_n^2. Of particular interest is the higher value curve ($C_T^2 = 2e-4$) since it nearly follows the CLEAR 1 profile from about 16 km to 27.5 km altitude.

The first instrumented flight using the balloon-ring platform used four high speed temperature sensors mounted on a 3m boom that was attached to the ring at the middle of the boom. Sensors were located at each end of the boom, 25 cm from one end, and 1m in from the same end. PSDs of these measurements are shown in Figure 4 for the altitude range 5057 m to 5282 m. Overall the results nearly follow a -5/3 slope, however there are a few artifacts at discrete wavenumbers. Although difficult to see from the black and white graph, the probe with the greatest effect is at the end of the boom that contained two other sensors. This is followed by the probe at the other end of the boom, the probe at 25 cm in, and the sensor at 1 m from the end. Since the boom represents a clamped-free bar, the modes for this configuration were calculated using:

$$\upsilon_n = \frac{\pi}{2l^2}\sqrt{E\frac{k^2}{\rho}\beta_n^2}$$

where E = Young's modulus, ρ = density, l = length, and k =the radius of gyration for cross-section. The calculated frequencies matched the "spikes" shown in the PSDs very closely. The effect is the most sever at the ends of the boom at diminishes as the center mounting point is approached. This pattern is expected since the ends will move greater distances than the inner points.

In summary, the balloon-ring platform with fine wire sensors will provide a useful method to examine several turbulence issues. The platform performs exceptionally well with no spinning, twisting, or pronounced pendulum motion. The 1 1/4 µm diameter wires withstand the treatment in the field-such as the sudden acceleration during launches. The electronics work well and sense the full bandwidth required to meet the set goals. The only redesign that is required will be with the boom that mounts the sensors. This will be designed to minimize the vibrations and to increase the frequency of the modes so that they are above those of interest in the observations. Although only temperature sensors were presented here, velocity sensors will also be added for research programs.

5. FUTURE WORK

It is planned to conduct two tests during the year using the balloon-ring platform, each test of about one week in the field. Sensors can be located at different spacings, sampling rates, etc. from launch to launch to address different issues as emerge from "quick look" results of each flight. A variety of conditions will be covered during the measurement periods.

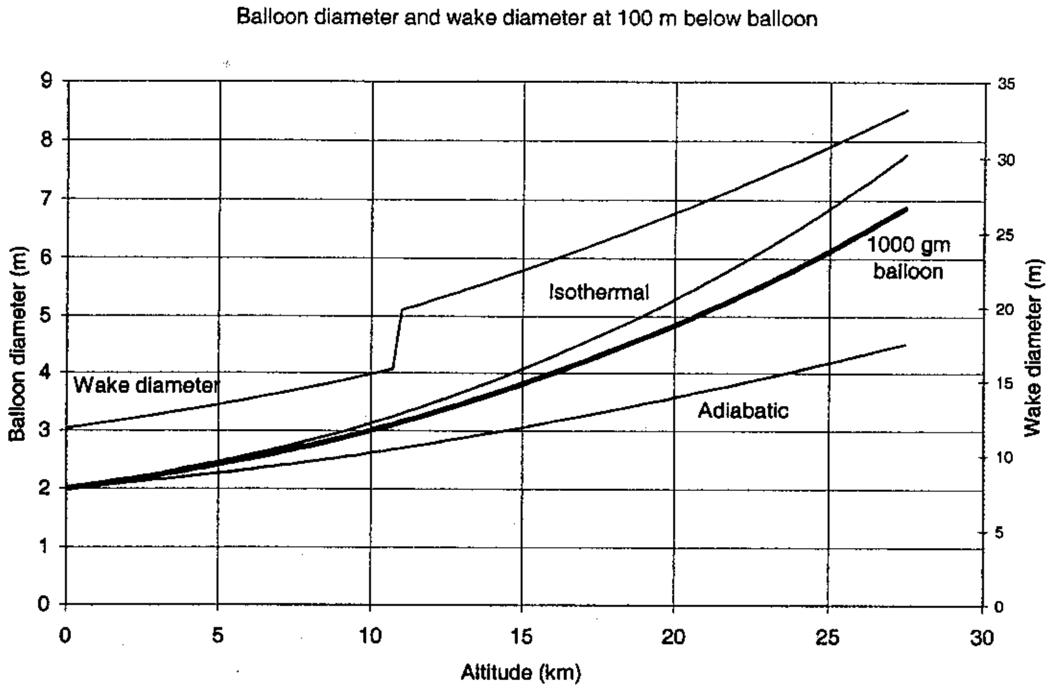

Figure 2: Estimated diameters of a 1000g balloon and associated wake.

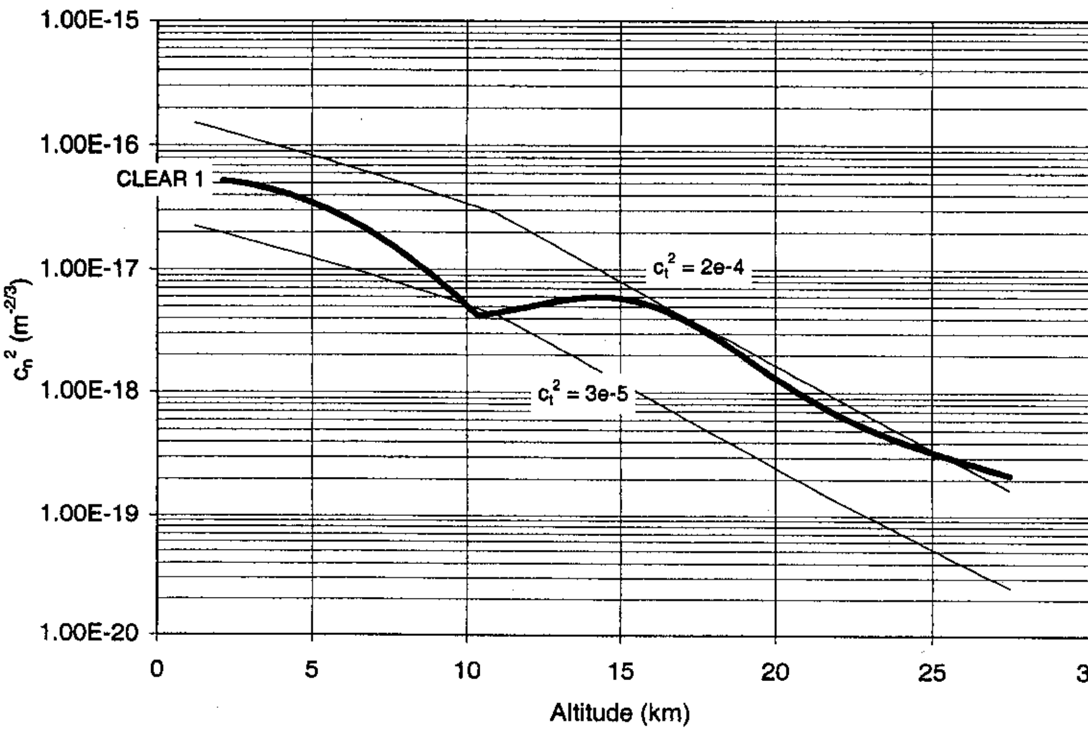

Figure 3: CLEAR I Profile and curves for two constant values of C_T^2.

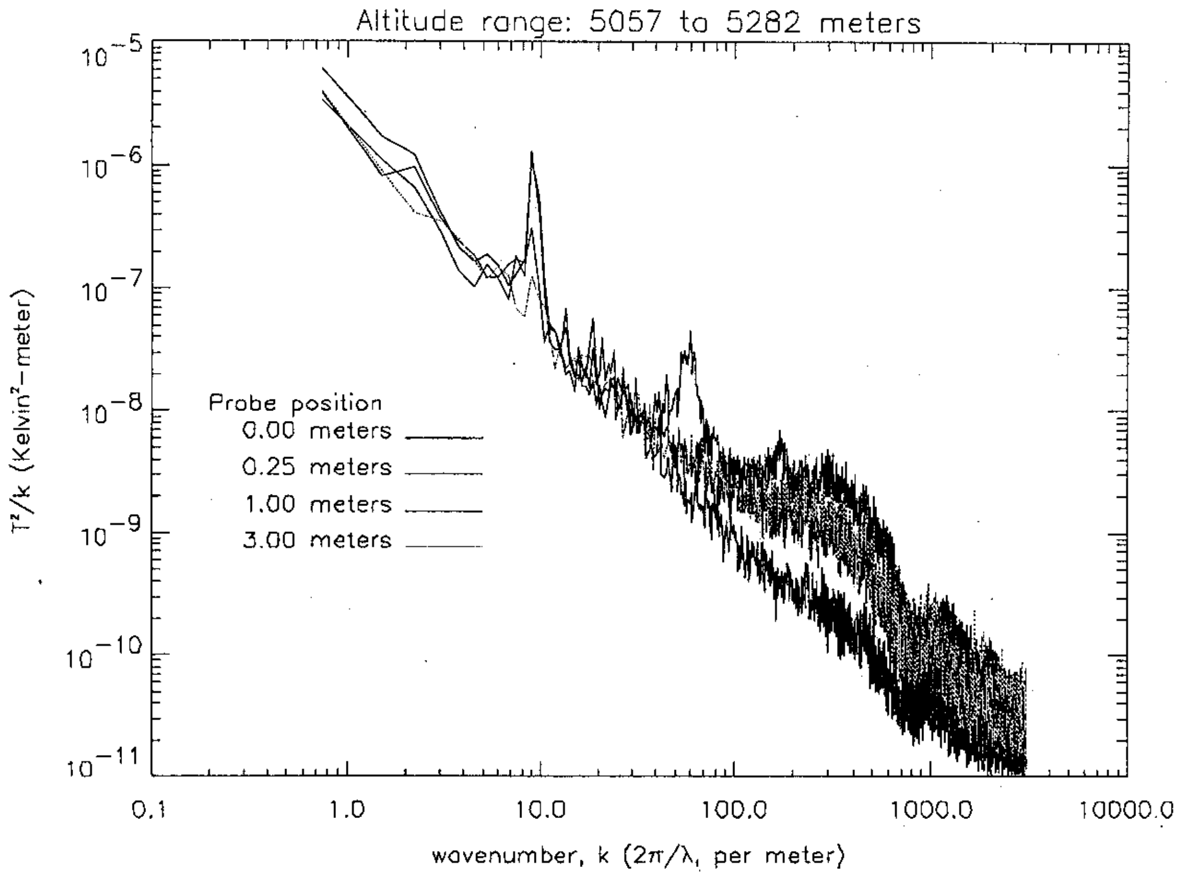

Figure 4: PSDs of four temperature sensors on the balloon-ring platform.

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